4. *Cenozoic Volcanism in Southwestern Japan with Special Reference to the History of the Setouchi (Inland Sea) Geologic Province.*

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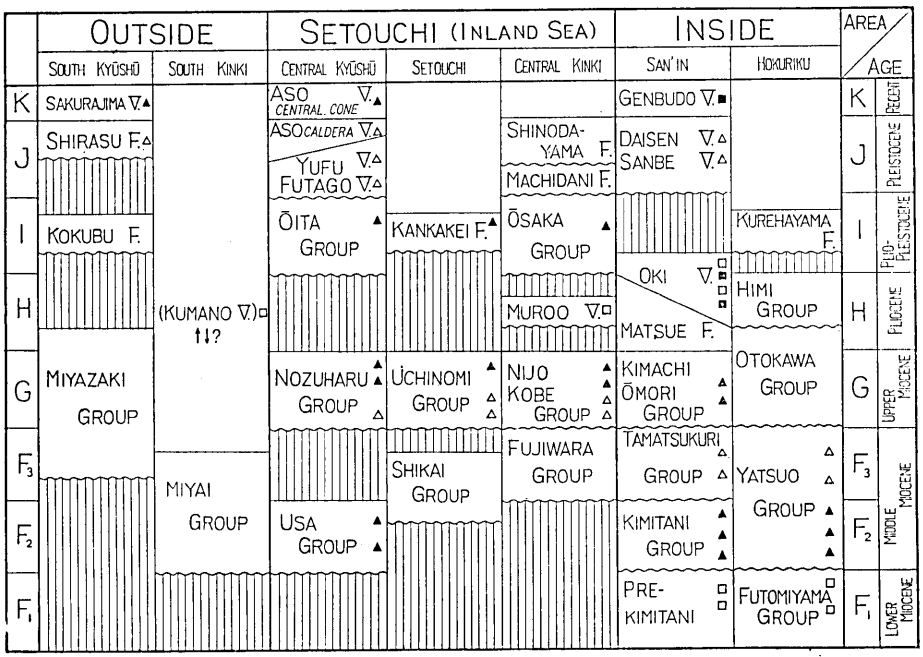
Introduction

The Cenozoic in Southwestern Japan may be divided into three geologic provinces, namely the Inside Geologic Province on the Japan Sea side, the Setouchi (Inland Sea) Province in the middle, and the Outside one on the Pacific side. The Setouchi Geologic Province roughly occupies the middle zone between the present mountain ridge of Chûgoku District and the Median Dislocation Line. It includes Central Kyûshû, the Inland Sea (Seto-naikai) and its environs, and central Kinki District, extending eastwards to the Shidara basin in Aichi Prefecture. In the Setouchi Province, occurrence of "sanukitoid", an aphanitic lava characterized with minute equigranular hypersthene crystals has been noted by some petrologists in relation to the problems of foreign contamination in these sanukitoid lavas. The type of sedimentation in the area was quite different from those of the Inside and Outside geosynclines. This fact has made it difficult to correlate stratigraphically the strata deposited in the area. Most of them were deposited in the inland sea or in fresh water lakes formed during Neogene on the basement mostly composed of granitic rocks. This paper includes an outline of the history of Cenozoic volcanism in the Setouchi Geologic Province with those in the Inside and Outside provinces in Southwestern Japan (Table I and Fig. 1).

1) K. SUGI, *Bull. Volc. Soc. Japan*, **4** (1938), 17-33 (in Japanese).
R. MORIMOTO, *Proc. 7th Pacific Sci. Cong.*, **2** (1953), 302-307.

Table I. Correlation table of the Cenozoic formations in Southwestern Japan.



I. Late Palaeogene crustal movements and the beginning of the Cenozoic volcanism in Southwestern Japan —Oligocene (E)[2] to the early Miocene (F_1)—

The rocks representing the volcanism of this period are a little alkaline acid volcanic rocks recently reported from many localities; such as lithoidite-nevadite association belonging to Futomiyama group[3] in Toyama Prefecture, most of the liparites and quartz-porphyries distributed on the ridge of Chûgoku District, the anorthite-liparites found from the base of the green tuff in Tôhoku District, etc. From Oligocene (E) to early Miocene (F_1), Japan had been a theatre of crustal movements: the Japan Sea and Fossa Magna were formed; the difference between structural features of Southwestern Japan and those of North-

2) N. IKEBE, *Jour. Polytechnics, Osaka City Univ. Ser. G*, **1** (1954), 73-86.

3) Oral Communication from Prof. N. Ikebe and Mr. T. Matsumoto of the Division of Geoscience, Institute of Polytechnics, Osaka City University.

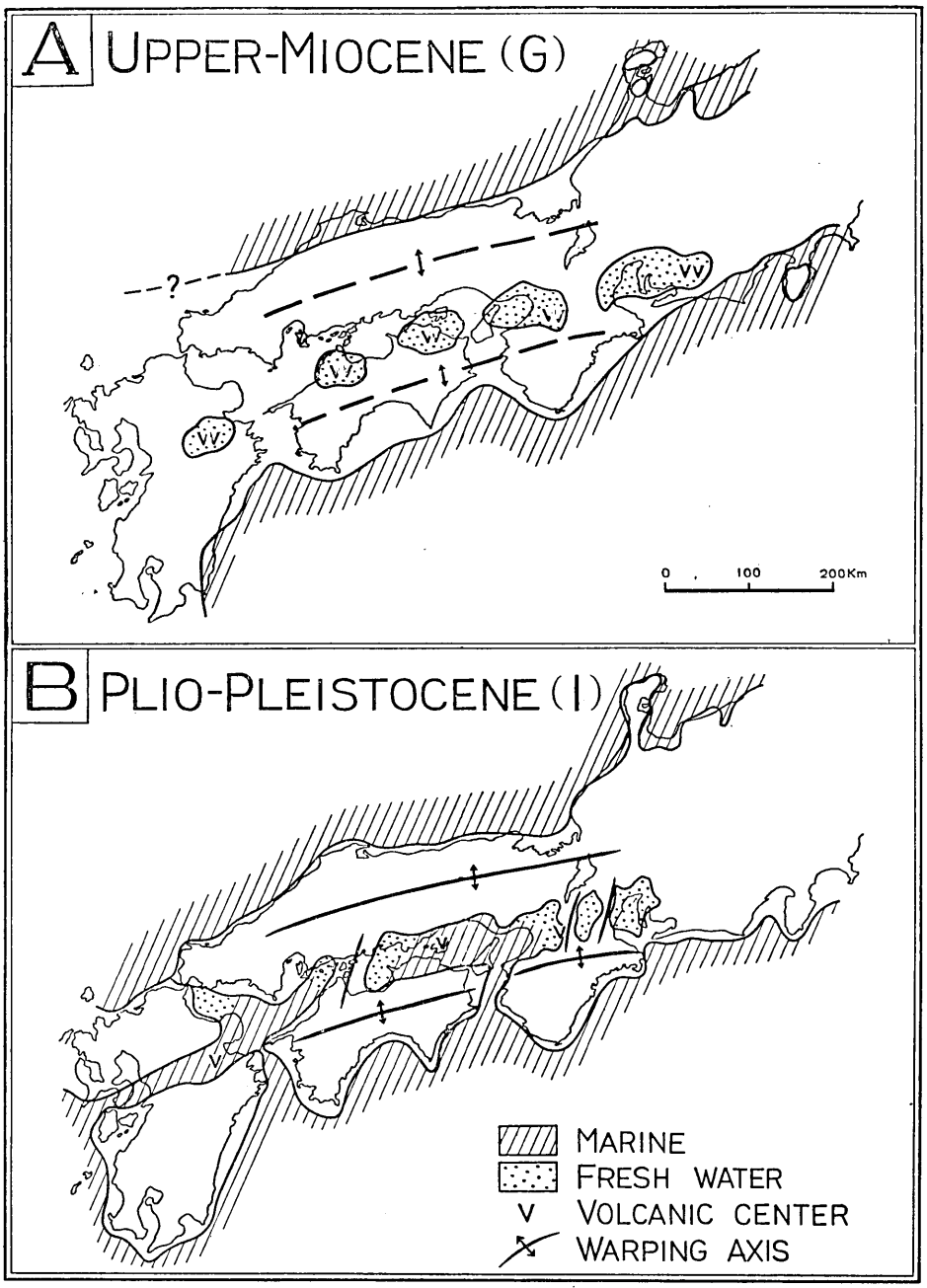


Fig. 1. Palaeogeographic maps of Southwestern Japan in the later Miocene (A) and in Plio-Pleistocene (B).

eastern Japan became distinctive; and the first remarkable volcanic activity in the Cenozoic era took place along with these movements.

II. Eruptions of "green tuff" and the birth of the 1st Inland Sea (Dai'ichi Seto-naikai) —Middle Miocene (F_2–F_3)—

After the movements of E–F_1 age the sea extended over the Japanese islands, and the geosyncline was formed in the area including the greater part of Northeastern Japan and the Inside Province of Southwestern Japan. The thick formations composed of lava flows and pyroclastics called "green tuff" were deposited on the base of this geosyncline. As a whole, the rocks erupted during this "green tuff" activity which are locally different in their petrographic characters may be divided into two groups, the tholeiitic basalts-andesites of F_2 stage and the dacites-liparites of F_3 stage[4]. They had been usually altered by hydrothermal solutions remarkably into one of the most important country rocks of Japanese mineral resources. Many replacement deposits of copper, zinc, and lead and many gold-silver-quartz veins are worked in them.

In middle Miocene, transgression of the sea along the median zone of Southwestern Japan progressed to form an inland sea spreading in the E–W direction there. This is the 1st Inland Sea (Dai'ichi Seto-naikai). Sediments of Mizunami, Fujiwara, Shikai groups, etc., were deposited in the shallow sea. Mizunami group[5] distributed in Gifu Prefecture is one of the most representative sediments deposited in the 1st Inland Sea and contains *Vicarya yokoyamai, Vicaryella ishiina, Miogypsina kotoi, Operculina complanata japonica*, etc. These fossil fauna are characteristic to $F_2 \sim F_3$ stage of Japanese Islands. *Desmostylus japanica* also was found in this group.

The volcanic rock representing the volcanism of "green tuff" in the Setouchi Province is the propyrites of Usa group in Central Kyûshû. No other remarkable volcanic activities were found in this period. The only thing to indicate a trace of volcanism is the tuff beds intercalated in the above-mentioned formations.

In the Outside Province, geosyncline was formed during this period where the formations belonging to Miyai and Miyazaki groups were deposited. No traces of volcanic activity were found in these sediments.

4) *Ibid.* 3).

5) K. HUZITA and S. OGOSE, *Jour. Geol. Soc. Japan*, **56** (1950), 482-492 (in Japanese).

III. Activity of Setouchi Volcanic Series —Later Miocene (G)—

The 1st Inland Sea had changed to a range of fresh water lakes owing to deposition of sediments or to upheaval of the land. In these lakes were deposited the formations of Nijô, Kôbe, Uchinomi, and Nozuharu groups composed mainly of the pyroclastics supplied by the activity of the so-called Setouchi Volcanic Series[6]. These formations contain plant fragments only as their fossil remains and no other palaeontological data available to determine their geologic age have been found. The writers however plot them to Upper Miocene (G) on the correlation table (Table I) based upon the following geological evidences[7]: *a) These formations were deposited successively on the sediments of the 1st Inland Sea and are overlain unconformably by the formations of the 2nd Inland Sea (Daini Seto-naikai) and b) the fossil flora contained in the Kôbe group may indicate upper Miocene age.*

The activity of the so-called Setouchi Volcanic Series began with effusions of rhyolites or pitchstones followed by outflows of biotite-andesites, hornblende-andesites, and pyroxene-andesites and finished in extrusions of aphanitic lavas of hyperthene-andesites or dacites called "sanukites". Petrographically they are andesites-dacites of calc-alkaline series and belong to "hypersthenic rock series"[8]. As indicated in the diagram (Fig. 2) chemical compositions of the lavas intercalated in the Nijô group are plotted nearly on the B–A–D–R Line of Daly's average compositions of the world basalt-andesite-dacite-rhyolite. Eruption of Setouchi Volcanic Series took places side by side in the five volcanic centres such as Shidara in Aichi Pref., Yamato in Nara and Osaka Prefs., Sanuki in Kagawa Pref., Iyo in Ehimé Pref., and Bungo in Oita Pref., which are arranged at intervals of about 100 km distance along the Median Line. These centres of activity accord with the situations of the fresh water lakes formed in later Miocene and with the warping axes of the Pleistocene-Recent movement in this region. The structural unit with an area of 100 km × 100 km and 30–50 km in depth is revealed

6) The term "volcanic series" differs in meaning from "volcanic zone" or "magma series". It contains a time-concept in addition to geographical distribution of volcanoes. It means the distribution of a group of certain volcanoes in space and time. Thus, Setouchi Volcanic Series in this paper includes only the volcanic rocks erupted in Setouchi Province during G-stage.

7) R. MORIMOTO, et al., *Jour. Geol. Soc. Japan*, **58** (1952), 342–343 (in Japanese). H. KUNO, *Trans. New York Acad. Sci., Scr.*, [ii], **14** (1952), 225–231.

8) H. KUNO, *Bull. Geol. Soc. Amer.*, **61** (1950), 957–1020.

Table II. Chemical composition of the lavas erupted from Nijô volcano near Osaka in G-stage.*

Constituents	N_1	N_2	N_3	N_4	N_5	N_6	N_7
SiO_2	61.50	61.72	60.19	61.67	64.55	64.58	70.52
Al_2O_3	17.52	19.18	17.29	17.92	16.73	18.05	13.48
Fe_2O_3	0.77	0.53	1.47	0.41	3.04	2.34	1.36
FeO	4.70	4.11	3.77	3.91	1.37	0.73	0.94
MgO	2.74	2.12	2.00	1.52	1.37	0.87	0.58
CaO	5.31	5.59	5.49	4.77	3.88	5.02	2.63
Na_2O	2.22	2.65	3.41	3.00	3.78	2.60	2.08
K_2O	1.88	1.99	1.85	2.42	2.52	2.23	2.94
H_2O (+)	1.96	0.45	2.86	0.87	1.33	0.58	4.27
H_2O (−)	0.37	0.23	0.49	0.53	0.96	1.69	0.98
TiO_2	0.81	0.62	0.70	0.60	0.58	0.53	0.16
P_2O_5	0.20	0.18	0.12	0.18	0.12	0.25	0.18
MnO	0.13	0.10	0.07	0.11	0.08	0.03	0.02
CO_2				1.66			
Total	100.11	99.47	99.71	99.57	100.31	99.50	100.14

* Garnet crystals are spersely contained in all of these lavas.

N_1: Hata-lava, porphyritic hypersthene-andesite.**

N_2: Kasugayama-lava, sanukite, an aphanitic hypersthene-andesite**.

N_3: Kôtoku-lava, sanukite, aphanitic hornblende bearing hypersthene-andesite, Anal. J. Ossaka, Earthquake Research Institute.

N_4: Ishikiriba (quarry)-lava, garnet-biotite-dacite, Anal. S. Tanaka, Earthquake Research Institute.

N_5: Odake-lava, aphanitic hornblende bearing hypersthene-dacite, Anal. J. Ossaka, Earthquake Research Institute.

N_6: Myôjinyama-lava, hornblende bearing hypersthene-plagioliparite**

N_7: Rokuyaji-lava, biotite-pitchstone (Y. KAWANO, *Rep. Geol. Surv. Japan* **134** (1950), 1–29 (in Japanese).)

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in the recent crustal deformation and seismic activities in this region[9].

The Inside Zone subsided greatly in the later Miocene to deposit thick strata of black shale in its basin and was in a comparatively calm state, though there occurred eruptions of andesites and deposition of

9) H. KAWASUMI and Y. SATÔ, *Spec. Bull. Earthq. Res. Inst.*, **5** (1947), 1-36 (in Japapese).

Table III. Chemical composition of some lavas from Muroo volcano, Mt. Mikasa, Central Kinki District, and from minor volcanic bodies near Osaka.

Constituents	M_1	M_2	M_3	S_1	S_2	S_3	S_4
SiO_2	72.55	71.15	57.42	51.72	52.40	57.24	64.02
Al_2O_3	13.17	13.03	16.79	15.71	16.94	15.31	15.42
Fe_2O_3	1.84	1.15	2.10	2.15	2.23	1.82	1.78
FeO	0.88	1.43	5.22	5.65	5.55	4.81	2.43
MgO	0.61	0.53	4.49	9.89	7.65	7.52	4.45
CaO	1.19	1.28	6.39	7.86	7.69	5.71	2.93
Na_2O	2.87	3.28	2.96	2.74	2.45	2.91	3.45
K_2O	3.97	4.23	2.18	0.79	1.15	1.46	2.57
H_2O (+)	1.48	2.63	1.65	2.30	1.06	1.76	2.32
H_2O (−)	0.97	0.32	0.36	0.85	1.05	0.39	0.38
TiO_2	0.24	0.27	0.73	0.58	1.01	0.54	0.42
P_2O_5	0.10	0.17	0.01	0.07	0.16	0.18	0.04
MnO	0.05	0.05	0.11	0.14	0.15	0.11	0.09
Total	99.92	99.52	100.44	100.45	99.49	99.76	100.30

M_1: Hypersthene-biotite-liparite from Kôchikei, Muroo, Mie Pref., Anal. J. Ossaka, Earthquake Research Institute.
M_2: Hypersthene-biotite-liparite from Hayama, Tsugeno, Nara Pref., Anal. J. Ossaka, Earthquake Research Institute.
M_3: Augite-hypersthene-andesite from Mt. Mikasa, Nara, Anal. J. Ossaka, Earthquake Research Institute.
S_1: Augite-olinine-basalt from Mt. Shigi, Nara Pref., Anal. J. Ossaka, Earthquake Research Institute.
S_2: Olivine-augite-basaltic andesite, Shibayama, Kokubu, Osaka Pref., Anal. T. Kushida, Geological Survey of Japan**.
S_3: Olivine augite-hypersthene-andesite from Shionomiya near Nagano, Osaka Pref., Anal. J. Ossaka, Earthquake Research Institute.
S_4: Biotite-quartz-hypersthene-andesite, a hybrid rock, from Terayama, Minamikawachi, Osaka Pref., Anal. J. Ossaka, Earthquake Research Institute.

the pyroclastic sediments such as Omori group[10]. These volcanic rocks also are of hypersthenic rock series as those of Setouchi Volcanic Series.

IV. Period of peneplanation —Pliocene (H)—

The Miocene sea had regressed from the Inside and Outside provinces in Pliocene age and left there local sedimentary basins. The 1st Inland Sea also had quite disappeared; deposits of the 1st Inland Sea were eroded with the basal granitic rocks to form peneplains. An event

10) T. TOMITA and E. SAKAI, *Jour. Geol. Soc. Japan*, **45** (1938), 529-531 (in Japanese).

of this age were the eruptions of Muroo welded tuff that took place on the Central Kinki District and covered an area of about 28 *km* in EW and 15 *km* in NS. The Muroo volcanic rocks are a little alkaline plagioliparite sometimes containing anorthoclasses (Table II).

In the Outside Province, Kumano Acidic Rocks intruding into Miyai group (F_2–F_3) are notifiable. The liparites containing potash felspar played an important rôle in its activity and formed welded tuff locally. Eruptions of the acidic rocks may be considered to have taken places probably in late Miocene or in Pliocene.

In the Inside Province, sediments of Pliocene are locally distributed such as Himi group in Toyama Pref., Matsue formation in Shimané Pref., etc. Eruptions of alkaline olivine-basalts, trachytes, alkaline rhyolites took places on Oki island in this age[11]. Trachyandesites and a little alkaline liparites extruded from the coast of San'in District[12].

V. Appearance of the 2nd Inland Sea —Plio-Pleistocene (I)—

Present shape of Japanese islands were formed in this stage. In the Setouchi Province, the 2nd Inland Sea (Daini-Seto-naikai) was widely extensive including the present Inland Sea, Central Kinki, and Central Kyûshû. Formations of Osaka, Akashi, Oita groups, etc., are the deposits in the Sea. *Metasequoia*, *Glyptostrobus*, *Liquidambar*, etc.,[13] are found in the lower portion of these formations (I_1) with *Stegodon akashiensis*. *Stegodon orientalis*, *Elephas naumanni*, etc., are found in the upper portion (I_2). As the volcanic rocks related to this stage, some of the Tsukushi lavas in Central Kyûshû[14], Kankakei lavas of Shôdo island, Kagawa Pref.[15], and pyroxene-andesites of Mt. Mikasa, Nara Pref.[16], may be pointed out. In association with these andesites, olivine-basalts or dolerites are found. The basalts and its derivatives are distinctive in composition from those of upper Miocene (Fig. 2 and Table III).

VI. Volcanoe of San'in and Ryûkyû Volcanic Zones —Pleistocene (J) to Recent (K)—

The present Inland Sea had retired from the drama of volcanism and Central Kyûshû appeared on the stage instead the former. In Pleisto-

11) T. TOMITA, *Jour. Shanghai Sci. Inst.*, **11** (1933), 37–146.
12) M. MUKAE, *Jour. Sci. Hiroshima Univ., Series C.*, **1** (1954), 51–60.
13) K. HUZITA, *Jour. Polytechnics Osaka City Univ., Ser. G*, **2** (1954), 75–85.
14) GEOLOGICAL SURVEY OF JAPAN, 1:500,000 Geological Map "Fukuoka" (1951).
15) GEOLOGICAL SURVEY OF JAPAN, 1:75,000 Geological Map "Saidaiji" (1934).
16) S. KOKAWA, *Jour. Geol. Soc. Japan*, **60** (1954), 487–493 (in Japanese).

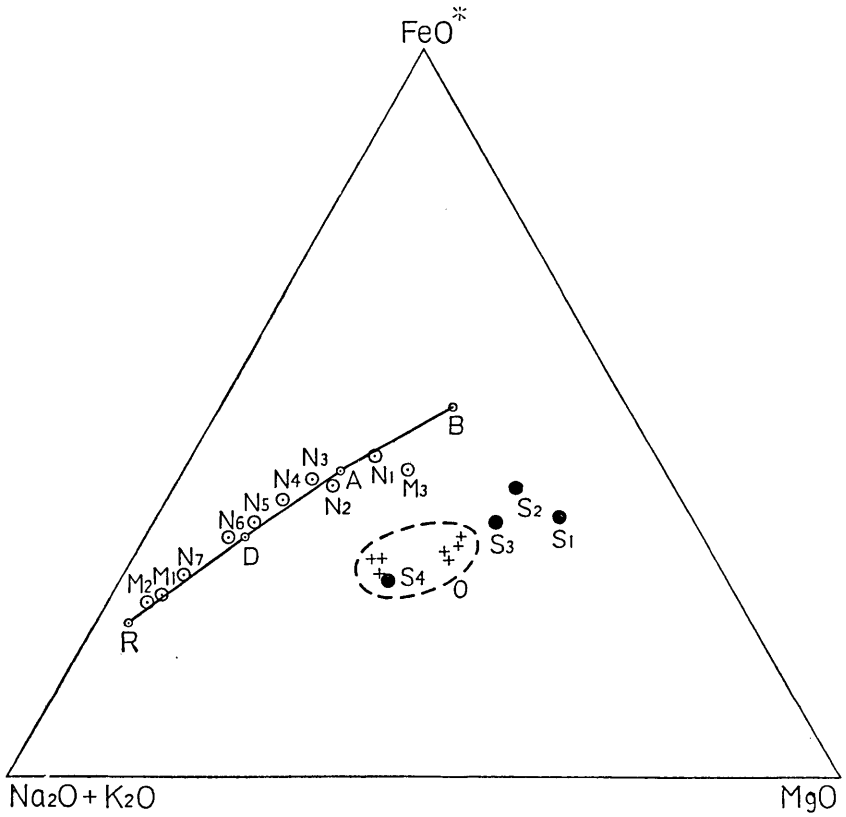

Fig. 2. FeO–MgO–Alkalis ratio of some lavas from the Setouchi Geologic Province. N_1–N_7: Lavas erupted from Nijô volcano in G-stage, M_1–M_2: Liparites from Muroo volcano, M_3: Pyroxene-andesite from Mt. Mikasa, S_1–S_4: Basalts and andesites erupted from the minor volcanic bodies near Osaka in I-stage, +-plotted in the area O surrounded by a broken line: Andesites from Otozan, Shôdoshima, Kagawa Pref. (M. YAMAGUCHI, *Sci. Rep. Geol. Inst. Kyushu Univ.* **3** (1951), 105–126 (in Japanese).), FeO*: Total iron oxides, sesquioxide being recalculated as ferrous oxide and added.

cene, Futagoyama, Unzen, Yufu, etc., in Central Kyûshû and Daisen, Sanbe, Aonoyama, etc., in the Chûgoku District were formed. Main activity of these volcanoes belonging to San'in or Daisen Volcanic Series[17] was following by the activity of the volcanoes of the Ryûkyû Zone; somma volcanoes of the great calderas began to outbreak[18]. After remarkable collapse-calderas formation characterized by extensive welded tuff distribution around them, central cones were formed in them in

17) T. KASAMA, *Jour. Polytech. Osaka City Univ.*, **1** (1954), 59-67.
18) T. MATSUMOTO, *Jap. Jour. Geol. Geogr.*, **19** (1943), Special Number.

Recent age which are still active now. Besides the activity of the above two volcanic zones, olivine-basalt magma and its derivative erupted to form many small volcanic bodies in the Inside Province represented by Genbudô basalt in Hyôgo Pref., etc.

Through the history of volcanism mentioned above it may be noticed that volcanic activity takes place in intimate relation with the development of sedimentary basins.

In conclusion, the writers wish to have an opportunity of expressing their sincere thanks to Prof. Nobuo Ikebe and Mr. Takashi Matumoto of the Osaka City University for their kind suggestions throughout this study. They also wish to acknowledge that a part of the expenses necessitated by this study have been defrayed from the fund for Scientific Research from the Ministry of Education of the Japanese Government.

4. 瀬戸内地質区を中心とした西南日本の新生代火山活動

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西南日本新生界は，中央構造線に沿う瀬戸内地質区を中軸に，内側地質区，外側地質区に三分される．瀬戸内地質区は，地向斜的性格を持つ内側及び外側地質区と異なり．不安定な内海または淡水湖に形成された堆積区で，地層の不連続と岩相変化の著しいこととにより，これまで地層の対比が充分に行われなかつた．筆者らは 1950 年以来，瀬戸内地域の火山層序学的研究を進め，堆積盆地の形成発達の経過と新生代火山活動の時代的変遷を調べたので，ここに瀬戸内区の火山活動と地史を中心に西南日本新生代火山活動史の概略を述べることにする．

1. 古第三紀末の地殻変動と初期の火山活動 —漸新世 (E)～中新世期 (F_1) —: 日本列島全域が著しい変動を受け，日本海・フォッサ・マグナが形成され，東北日本・西南日本の構造区分が明らかになつた．最近，北陸地方の Lithoidite-nevadaite-association からなる太美山層群がこの時期のものであることが明らかにされた．西南日本では中国脊梁山地の石英粗面岩・石英斑岩の大部分，東北日本ではグリン・タフの基底をなす anorthoclase-liparite などがこの期のもので，酸性岩で特徴づけられる．太美山期の火山岩類・火山砕屑岩は，構造上，以後の新第三系の基盤をなしている．

2. グリン・タフ期と第一瀬戸内海の形成 —中新世中期 (F_2-F_3)—: 大変動後の広汎な海侵により東北日本の大半と西南日本の内側に形成された一連の地向斜に，グリン・タフといわれる熔岩流及び砕屑物からなる厚層が累積する．西南日本中軸には東西に伸びた内海「第一瀬戸内海」が形成され，瑞浪・藤原・四海層群など浅海性の地層群が堆積する．瀬戸内区のグリン・タフ期の火山活動としては，九州中部の変朽安山岩からなる宇佐層群がある以外に，顕著な活動はなく，前記の地層群に含まれる凝灰岩に，わづかに火山活動の余波が窺われるだけである．第一瀬戸内海を代表する瑞浪層群に産する *Vicarya yokoyamai, Vicaryella ishiiana, Miogypsina kotoi, Operculina complanata japonica* などのが，この時期の特徴的な化石群である．外側区では，この時期に地向斜性の宮井層群・宮崎層群が沈積し，火山活動は知られていない．

3. 瀬戸内火山系の活動 — 中新世後期 (G) —: 第一瀬戸内海は，東西に配列する淡水湖列となり，そこに火山砕屑物を主体とする二上・神戸・内海・野津原の各層群が堆積する (第 1 図). この地層群に物質を供給したのが瀬戸火山系の活動である．これらの地層群は，その地質時代論に問題を残していたが，第一瀬戸内海の海成層に引続いて堆積し，後述する第二瀬戸内海の地層群に不整合におおわれることと，神戸層群中の植物化石群の指示するところに従つて中新世後期 (G) とした．瀬戸内火山系の活動は，流紋岩・凝灰岩などの酸性岩に始まり，黒雲母安山岩・角閃安山岩を引続いて噴出し，特異な讃岐岩の噴出で終つている．その代表的な二上山のこの時期の熔岩は，典型的な紫蘇輝石質岩系に属する (第 2 図及び第 2 表). また，瀬戸内区における火山群の噴出が，設楽・大和・讃岐・伊予・豊後と，中央構造線に沿い 100 *km* の等間隔に配列しているのは興味深い点である．中新世後期の内側区では，地向斜の沈降が進み黒色頁岩の堆積が続き比較的平穏であつたが，山陰地方では，やはり紫蘇輝石質岩系の安山岩を主とする火山活動が続き大森層群に物質を供給した．

4. 陸化削剥期 — 鮮新世 (H) —: 西南日本は全般的に陸化し，内側・外側両区は一部堆積盆地を残して海退し，瀬戸内地質区も，第一瀬戸内海は完全に消滅し，その堆積物は，基盤岩類とともに削剥され準平原化が進んだ．この時期に近畿中央部に東西 28 km 南北 15 km の広域にわたる，大部分が熔結凝灰岩からなる室生の plagioliparite が噴出した．外側区では宮井層 (F_2-F_3) を貫く熊野酸性岩類の活動が知られているが，活動の時期ははつきりしない．内側区でも海退が進み，北陸地方の氷見層群，山陰地方の松江層など一部地層の形成を見たにすぎない．日本海の隠岐道後のアルカリ岩の噴出は，この時期に行われ，山陰海岸にも，粗面安山岩などの噴出を見ている．

5. 第二瀬戸内海の出現 — 鮮新洪積世 (I) —: 内側・外側の海岸線は，ほぼ現在の形に近づき，瀬戸内区では先に消滅した第一瀬戸内海の跡に，新しい内海「第二瀬戸内海」が生じた．この内海の分布は，現在の瀬戸内海より広く，東は近畿中央部，西は九州にまで及び，大阪層群・明石層群・大分層群が堆積した．この地層の下部 (I_1) からは，*Metasequoia*, *Glyptostrobus*, *Liquidambar* など日本列島では鮮新世末に絶滅した植物化石群を産する．第二瀬戸内海に堆積した地層群に夾在する凝灰岩によつてこの時期の火山活動が知られるが，火山岩体としては，九州中部の筑紫熔岩の一部，小豆島の寒霞渓熔岩，三笠山安山岩など複輝石安山岩を主とする活動がある．この安山岩に伴い橄欖石斑晶を多量に含む粗粒玄武岩 — 玄武岩 — 玄武岩質安山岩の噴出が小豆島，二上山近傍，鍋山，三笠山などで明らかになつている．後者は，苦土質に富み，G 期の噴出岩と異なる化学成分を示す (第 2 図及び第 3 表).

6. そのごの火山活動 — 洪積世 (J) ～沖積世 (K) —: 洪積世に入つて，瀬戸内区の西端に当る九州中部に，両子・由布・雲仙などの諸火山が噴出し，角閃安山岩からなる円頂丘を形成した．この火山列の延長は，本州を縦走して山陰に至り，三瓶・青野・大山など「山陰 (大山) 火山系」に属する一連の火山を噴出している．ついで九州中部では，山陰系火山の活動に引続き，阿蘇・恰良・阿多・鬼介の大規模なカルデラの形成，それにつぐ現在の中央火口丘群の噴出，琉球弧北側に分布する活火山群の活動を見るに至る．山陰・琉球の二つの火山系のほかに，西南日本内側では玄武洞を典型とする玄武岩質岩石の小火山丘が，山陰から北九州にかけて形成されている．以上の西南日本における新生代火山活動の推移を見れば，堆積盆地の形成と密接な関連を以つて火山活動が行われていることが知られる．